FOREST SERVICE
U.S. DEPARTMENT OF AGRICULTURE
INTERMOUNTAIN FOREST AND RANGE EXPERIMENT STATION
507 — 25th Street, Ogden, Utah 84401

USDA Forest Service
Research Note INT-256

February 1979

SOME CHEMICAL CHARACTERISTICS OF GREEN AND DEAD LODGEPOLE PINE AND WESTERN WHITE PINE[1]

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ABSTRACT

The chemical components and combustion characteristics of dead and live lodgepole pine and western white pine were determined. Except for small variations, the chemical composition and burning characteristics of sound dead wood were nearly identical to the corresponding live wood for both species. Therefore, dead wood could be utilized as a source of chemicals, fuel, and as a substitute for live timber in the manufacture of wood products.

KEYWORDS: chemical components, combustion characteristics, dead trees, lodgepole pine, western white pine, utilization of dead trees

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[1] This report was prepared as a cooperative project of the Intermountain Forest and Range Experiment Station, Ogden, Utah, and the Wood Chemistry Laboratory, University of Montana, Missoula.

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INTRODUCTION

The Western United States, particularly the Northern Rocky Mountains, contains vast quantities of dead lodgepole pine (*Pinus contorta* var. *latifolia* Engelm.) and western white pine (*Pinus monticola* Dougl.) trees. Unchecked insect and disease attacks are adding to the volume of dead timber. Although utilization of dead timber is gradually increasing as land managing agencies require its removal from sales areas, only a small percentage of the dead trees are being harvested and used. A recent survey, cited more than 7 billion board feet (about 28 million m^3) of dead timber in the Rocky Mountain States (Green and Setzer 1974). Furthermore, annual mortality is estimated to be 0.3 billion ft^3 (approximately 8.5 million m^3). The mortality rate will probably continue or possibly increase until the present overmature stands have been decimated or brought under management. The dead timber is thus a largely untapped reservoir of potentially utilizable material.

The principle deterrent to the use of dead timber is the lack of knowledge on the chemical, physical, and mechanical properties of this wood. The long exposure time under natural forest conditions may have adversely altered some of those desirable qualities present in green wood. This paper reports the results of chemical analyses for extractive content, cell wall components, and combustion characteristics of living and dead (standing and down) lodgepole pine and western white pine. The chemical characteristics of their "dead" wood were compared with the characteristics of "live" wood to determine the similarity and suitability for like products. Sample material was obtained from a single tree of each type for the two species.

Collecting and Testing Wood Samples

Lodgepole pine samples were obtained in June from trees on the Bitterroot National Forest, white pine samples in September from the Lolo National Forest. (Both Forests are in western Montana.) The selected trees one of each type, either green, dead down in contact with the ground, or dead standling, were approximately 8 inches (20.3 cm) in diameter. After felling, the trees were cut into short section, approximately 20 inches (50.8 cm) long and the sections were taken to the laboratory. Only sections with sound wood were taken from the Forest. At least 10 sections were obtained from each tree. The dead lodgepole pine had no bark whereas the dead white pine trees had retained the bark.

In the laboratory the sections were split longitudinally with an ax and the outer 1/2 inch (1.27 cm) (sapwood) was split off using a hammer and chisel. Sample material was also split off the heartwood portion of the chunks. These pieces were further reduced in size to approximately 3/8 by 3/8 by 5 inches (0.95 by 0.95 by 12.7 cm). The bark and cambium layers were peeled from the green tree pieces to prepare them for grinding.

The smaller size pieces were ground in a Wiley mill to pass through a 40-mesh screen. The identity of the sample material was retained throughout the preparatory process. A total of 12 samples were prepared, about 5 pounds (approximately 2.3 kg)

in each. For each species, the samples were: green heartwood, green sapwood, dead standing heartwood, dead standing sapwood, down heartwood, and down sapwood. The ground samples were thoroughly mixed, stored in polyethylene bags, and refrigerated, to prevent the growth of mold and stain fungi, until required for analysis.

Samples of sapwood and heartwood of each wood type were used to determine moisture content and specific gravity. Moisture content (percentage) was determined by the ovendrying method and specific gravity was based on green volume-ovendry weight.

All chemical analyses were made in duplicate, and because of the small sample quantities, all weights were made to the nearest 0.0001 g. (Deviation of duplicated runs had to fall within 10 percent of their average value or the analysis was repeated until this criterion was met. For wood components constituting less than 3 percent of the raw wood, the criterion was expanded to 20 percent of the average value, and for materials less than 1 percent, it was expanded to 50 percent.) Where possible, analyses were made in accordance with procedures published by the American Society for Testing and Materials 1972. Ovendry weights of all sample materials and residues were used.

Ether and benzene-alcohol solubility determinations were made using 2-g samples of the unextracted wood (ASTM Standard Tests D1106-56 and D1107-56). The extractive results for all solvents were expressed as percentages of the original sample weights.

The hot water and caustic soda solubility determinations also used 2-g samples of unextracted wood. One hundred ml of distilled water and 100 ml of a 1 percent solution hydroxide (NaOH) were used in these extractions (ASTM Standard Tests D1110-56 and D1109-56).

The cell wall components were determined on an extractive free basis. The ground wood samples used in these analyses were successively extracted with benzene-alcohol (2:1, v/v), 95 percent ethyl alcohol, and hot water (ASTM Standard Test D1105-56).

A modified chlorite method was used to determine the holocellulose content (Browning 1967). Two grams of the extractive-free wood sample were delignified with sodium chlorite (200 g of sodium chlorite in 1 liter of water) and 40 ml of a buffer solution (60 ml of acetic acid and 1.3 g of sodium hydroxide in 1 liter of water) in a 250 ml Erlenmeyer flask. The delignification was carried out in a 75° ± 2°C water bath for 205 minutes with additions of 4 ml of the sodium chlorite solution at 0, 30, 60, 105, and 150 minutes. After 205 minutes, the digestion was stopped and the contents were washed into a gooch crucible with distilled water. Additional washings used acetone and distilled water. The white, fluffy residue, dried at 105°C, was termed holocellulose.

Alpha cellulose, that portion of holocellulose which is insoluble in 17.5 percent sodium hydroxide, was determined with 1-g samples of holocellulose as prepared above (ASTM Standard Test D1103-60).

Lignin is the residue or the portion of extractive-free wood that is insoluble in sulfuric acid (ASTM Standard Test D1106-56). Lignin residue in the holocellulose portion was determined by this same procedure and the value obtained was used to correct the results of the holocellulose and alpha cellulose determinations.

Hemicellulose was calculated as the difference between the lignin-residue-corrected original holocellulose weight and the final alpha cellulose weight.

A 2-g sample of unextracted wood was used to determine the ash content. The ash residue was expressed as a percentage of the original sample weight (ASTM Standard Test D1102-56).

The percentage of char was determined from a 1-g sample of unextracted wood placed in a preweighed dry aluminum foil pan. The sample was heated to 752°F (400°C) at a rate of 15°/minute under flowing nitrogen (200 ml per minute) in a tube furnace and was kept at this temperature for 10 minutes. The yield of char was weighed under nitrogen in a glove box, to prevent absorbtion of moisture.

The higher heating value of the char and of unextracted wood was determined in a Parr 1241 automatic adiabatic calorimeter. The heat value was expressed in megajoules per kilogram of ovendried wood.

Results and Discussion

Moisture Content and Specific Gravity

The green lodgepole pine had the highest moisture content in both the heartwood and sapwood. Average percentage moisture content of the green tree heartwood was 2 to 3 times the moisture content of the dead down and standing tree heartwood, and the green tree sapwood was 9 to 10 times the average percentage moisture content of the dead tree sapwood (table 1). The average specific gravity of the dead lodgepole pine was nearly identical to the green sample. The average specific gravity of the heartwood was greater than the sapwood average specific gravity in all three sample types, probably due to the greater extractive content in the heartwood.

Table 1.--*The average[1] percent moisture content and specific gravity of lodgepole and western white pine samples from green, dead down, and dead standing trees used for chemical analysis*

Analyses	Heartwood			Sapwood		
	Green	Dead down	Dead standing	Green	Dead down	Dead standing
			LODGEPOLE PINE			
Moisture content (%)	34.5 (7)	19.5 (7)	11.9 (5)	162.5 (5)	14.6 (8)	18.3 (5)
Specific gravity[2]	0.379 (20)	0.361 (10)	0.381 (12)	0.355 (15)	0.357 (14)	0.367 (9)
			WESTERN WHITE PINE			
Moisture content (%)	28.0 (2)	34.7 (2)	16.5 (2)	27.2 (2)	33.8 (2)	14.4 (2)
Specific gravity[2]	0.429 (2)	0.384 (2)	0.391 (2)	0.455 (2)	0.352 (2)	0.336 (2)

[1]The number of specimens used is indicated in parentheses.
[2]The specific gravity determinations were based on green volume and ovendry weight.

For western white pine the average percentage moisture contents of the dead down and green samples were nearly identical and about twice as high as the average percent moisture content of the dead standing sample material. The average specific gravity of the green white pine was greater than the average specific gravity of the dead down and dead standing sample material from both heartwood and sapwood. And, with the exception of the green heartwood, the average specific gravity of the heartwood was greater than the average specific gravity of the sapwood for the three wood types.

The absence of any large differences in the average specific gravity between the live and dead samples for both lodgepole and white pine suggests that the woods are physically similar.

Extractive Content

Wood extractives affect the manufacture of pulp, paper, paint, varnish, and

adhesives. Also certain amounts of some components enable the living tree to resist disease. The extractives contribute to many of the properties of wood in spite of their usually limited weight.

The extractives can be classified on the basis of their solubility in a specfic solvent; however, the solubility of the extractives in different solvents may overlap (Browning 1967). The total amount of extractives in these experiments was not additive because the extractions were not carried out consecutively on the same sample. The solvents used for analysis were ether, benzene-alcohol (2:1 by volume), hot water, and 1 percent solution of sodium hydroxide. Ether is best for the saponifiables and benzene-alcohol is the best solvent for the resin acids. Materials in wood that can be extracted with hot water and a solution of sodium hydroxide include inorganic salts, sugars, cycloses, coloring matters, gums, and some phenolic substances. Chemical analysis of the various solvent extractives was not a part of the study.

The results of the extractive determinations are shown in table 2. For lodgepole pine the ether and benzene-alcohol solvents removed a greater percentage of extractives from the green wood than from the dead tree wood. The hot water and sodium hydroxide solvents, with one exception, removed greater percentages of extractive material from the dead tree wood than from the green wood. There was no consistent difference between the heartwood and sapwood for the solvents used. In general, the heartwood tended to have greater extractive content for the ether, benzene-alcohol, and hot water solvents. However, the sapwood has a greater percentage of extractive soluble in sodium hydroxide.

Table 2.--*The percentage of extractive content*[1] *of green, dead down, and dead standing lodgepole and western white pine based on the ovendry weight of wood*

Solvent	Lodgepole pine						Western white pine					
	Heartwood			Sapwood			Heartwood			Sapwood		
	Green	Dead down	Dead stand	Green	Dead down	Dead stand	Green	Dead down	Dead stand	Green	Dead down	Dead stand
Ether	0.91	--	0.27	0.31	--	0.23	1.89	2.83	0.95	0.53	0.75	0.59
Benzene:alcohol (2:1 by vol.)	2.13	1.41	1.94	2.32	1.07	0.97	5.05	5.09	3.64	2.19	1.85	1.74
Hot water	3.04	3.21	5.53	2.37	2.36	3.79	4.24	4.85	4.83	2.27	3.17	2.68
1% NaOH	11.12	11.99	16.07	11.31	12.77	16.37	12.98	13.45	12.34	8.64	12.84	11.32

[1]The values are the averages of at least two determinations.

For western white pine the ether and benzene-alcohol again tended to remove greater percentages of extractive material from the green wood. No consistent trend was evident in the percentage of extractives removed by the hot water or sodium hydroxide solvents. The heartwood consistently had a greater percentage of extractive content than the sapwood, for all solvents used.

The white pine tended to have a greater amount of soluble extractive material than the lodgepole pine, perhaps because the white pine had not been dead for as long a time as the lodgepole pine.

Theoretically, holocellulose and lignin constitute the total volume of wood on the extractive-free basis. Holocellulose, the fibrous carbohydrate fraction, includes alpha-cellulose, which ideally yields only D-glucose on hydroysis, and hemicellulose, which contains xylans and glucomannans. Holocellulose constitutes the matrix of the cell wall and contributes to the elasticity and plasticity of the cell wall.

Lignin is present in the fine spaces within the cell wall where it acts as a bulking agent and reduces the dimensional changes in the cell wall. The rigidity of the lignin helps increase the cell wall stiffness.

For lodgepole pine the percentage differences between the green and dead wood samples were small, as were the percentage differences between heartwood and sapwood. The green wood of white pine had slightly higher percentages of holo- and alpha-cellulose. In all white pine samples, the sapwood had a higher alpha-cellulose and lower hemicellulose and lignin content than the heartwood (table 3).

The higher heating value of wood is primarily determined by its density and moisture content. Lignin content and, to a greater extent, the presence of extractives such as resins and tannins also affect the heating value. For the cell wall components, lignin is relatively heat stable (decomposes at 662° - 752°F (350° - 400°C)) followed by alpha-cellulose (392° - 572°F (200°-300°C)). Hemicellulose undergoes thermal decomposition at relatively lower temperatures.

Table 3--*Average percentage*[1] *of cell wall components of green, dead down, and dead standing lodgepole and western white pine based on extractive-free ovendry weight of wood*

	Lodgepole						Western white pine					
	Heartwood			Sapwood			Heartwood			Sapwood		
Component	Green	Dead down	Dead stand	Green	Dead down	Dead stand	Green	Dead down	Dead stand	Green	Dead down	Dead stand
Holocellulose	75.45	76.06	74.64	77.18	75.11	77.23	75.60	73.62	73.63	76.12	72.92	75.40
Alpha-cellulose	43.31	44.39	42.83	43.87	45.63	45.12	40.26	38.75	39.60	45.36	40.41	44.60
Hemicellulose	32.14	31.67	31.81	33.31	29.48	32.11	35.34	34.87	34.03	30.76	32.51	30.80
Klason lignin	27.14	26.60	27.99	26.85	27.49	26.75	28.04	28.73	27.88	25.75	26.81	25.84

[1]Each value is the average of at least two determinations.

The combustion characteristics of the lodgepole and white pine wood types are shown in table 4. In general, differences between wood types, heartwood and sapwood, and between species were small and inconsistent. The heartwood of both species did have a slightly higher heat content than the sapwood. This was probably due to the heartwood's higher resin content. Also, for the lodgepole pine the dead tree samples had a higher percent ash content. Windblown dust and soil were probably the responsible factors.

Table 4.--*The combustion characteristics*[1] *of ovendry samples of green, dead down, and dead standing lodgepole and western white pine*

	Lodgepole pine						Western white pine					
	Heartwood			Sapwood			Heartwood			Sapwood		
Characteristic	Green	Dead down	Dead stand	Green	Dead down	Dead stand	Green	Dead down	Dead stand	Green	Dead down	Dead stand
Higher heating value mJ/kg[2]	19.98	19.87	20.11	19.90	19.49	19.60	20.31	20.44	20.18	19.79	19.78	19.47
Yield of char[3] %	30.04	29.18	29.55	29.60	29.48	28.10	28.93	28.44	28.47	28.14	27.94	27.00
Higher heating value of char mJ/kg	29.77	30.14	30.23	30.28	30.15	30.31	31.17	30.99	31.17	31.27	31.12	31.07
Ash[3] %	0.34	0.43	0.55	0.36	0.51	0.53	0.36	0.28	0.30	0.29	0.29	0.23

[1]Each value is the average of at least two determinations.
[2]Megajoules per kilogram.
[3]Based on ovendry weight of wood.

The results of the chemical and physical determinations for green and dead wood of the two study species are summarized in table 5. This table also contains a listing of values, obtained from the literature, for the extractive contents and cell wall components. The table emphasizes the differences pointed out earlier and also indicates that the study data are, in general, comparable to published data. Differences can, perhaps, be attributed to the age, size, and location from which the different samples were taken.

Table 5.--*Summary of the chemical and physical characteristics of live and dead wood from lodgepole and western white pine*

Characteristics	Lodgepole pine			Western white pine		
	Lit.[1]	Green	Dead	Lit.[2]	Green	Dead
Specific gravity	--	0.367	0.367	--	0.442	0.366
Extractives[3]						
Ether	1.3	0.61	0.25	5.6	1.21	1.28
Benzene:alcohol (2:1 by vol.)	2.8	2.23	1.35	8.3	3.62	3.08
Hot water	3.7	2.71	3.72	3.7	3.26	3.88
1% NaOH	11.6	11.22	14.30	15.6	10.81	12.49
Cell wall component[3]						
Holocellulose	71.6	76.31	75.76	64.3	75.86	73.89
Alpha-cellulose	47.3	43.59	44.49	42.3	42.81	40.84
Hemicellulose	24.3	32.72	31.27	22.0	33.05	33.05
Klason lignin	25.9	26.70	27.21	25.4	26.90	27.32
Combustion						
Heating value[4]	--	19.95	19.77	--	20.05	19.96
Yield of char %	--	29.82	29.08	--	28.54	27.96
Heating value of char[4]	--	30.02	30.21	--	31.22	30.09
Ash %	0.2	0.35	0.51	0.3	0.33	0.28

[1]Data from: McGovern, J. N. 1951. (Pulping of lodgepole pine, USDA Forest Service FPL R1792, Madison, Wis.)

[2]Data from: Isenberg, I. H. 1951. (Pulpwoods of United States and Canada. Second Edition. The Inst. of Paper Chemistry, Appleton, Wis.)

[3]Values shown are percentages.

[4]mJ/kg (Megajoules per kilogram).

CONCLUSIONS

Tests of heartwood and sapwood from green, dead down, and dead standing lodgepole and western white pine indicated that the wood is chemically and physically similiar. Specific gravity was nearly the same for both green wood and dead wood, indicating no decay of the sample material. The sample from dead trees had a lower moisture content (percentage) than samples from the green trees. The extractive content for the green wood was slightly higher than for the dead wood. Percentages of cell wall components were essentially the same for the three wood types and the effect of species was small. Also, combustion characteristics were similiar. The study results, based on single trees of each type, indicate that wood from dead trees is comparable to wood from green trees. As a result, dead trees should be considered a source of chemicals, fuel, and new material for board, pulp, and paper.

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